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X.

SIR WILLIAM HERSCHEL'S OBSERVATIONS OF VARIABLE STARS.

By Edward C. Pickering.

Presented January 9, 1884.

The discovery last summer of two additional catalogues of the Light of the Stars by Sir William Herschel has been announced elsewhere. At the same time a Journal was found, which gives the dates of observation for the individual comparisons contained in the six catalogues. The suggestion was made by Mr. Chandler, that the observations of variable stars contained in these catalogues would thus be rendered of value. The observations contained in Table I. were kindly forwarded by Lieut. Col. Herschel, who has taken much trouble in furnishing me with all the material available for the following discussion. The successive columns of Table I. give a current number, the number of the catalogue of Herschel in which the star is contained, the usual designation of the star, and its Flamsteed number. The next columns give the date, the observation, and the resulting magnitude. The latter is derived from the photometric observations made in 1879–82 at Harvard College Observatory with the meridian photometer, and will appear in the Annals of the Observatory, Volume XIV. The values assumed for the intervals employed by Herschel are obtained from a discussion of all his catalogues, and will appear in the same volume; they are 0.1 for a period, 0.2 for a comma, and 0.4 for a dash.

The scale employed may be defined as that in which a magnitude corresponds to the ratio whose logarithm is four tenths, and which coincides with the scale of Argelander for the magnitude 5. It is best illustrated by the statement that the magnitudes 3, 4, 5, and 6 on the scales of the Uranometria Nova, Heis, and the Durchmusterung would be expressed by 3.1, 4.2, 5.0, and 5.8 on the photometric scale.

TABLE I.

No.	Cat.	Name.	Fl.	Date.	Comparison.	Magn.
1	I.	η Aquilæ	55	1795, July 19	65, 30, 55. 60	3.8
2		“		“ “	60. 55	4.1
3		“		“ “	55 — 41 — 38. 44	3.9
4		“		1795, July 25	41, 55	4 5
5	I.	*g* Herculis	30	1795, May 23	1, 30	4.7
6		“		1795, May 25	30 — 25	5.1
7		“		“ “	11. 35 — 6, 30	4.9
8		“		“ “	6, 52, 30	5.2
9		“		“ “	52, 42, 30, 34	5.6
10		“		1795, Sept. 20	30. 1	4.4
11		“		“ “	30 —, 25	4.9
12	I.	*u* Herculis	68	1795, May 22	71. 68, 72	5.2
13		“		“ “	68, 90, 72	5.1
14		“		1795, Aug. 18	68, 59, 61	5.1
15		“		“ “	69 — 68	5.3
16	II.	*o* Ceti	68	1779, Nov. 30	$\beta > o > \alpha$	2.4
17		“		1798, Feb. 18	68. 82	4.0
18	II.	η Geminorum	7	1795, Mar. 29	$\mu - \eta - \xi''$	3.3
19		“		“ “	$\mu - \epsilon - \eta$	3.6
20		“		1795, Nov. 7	27; 13, 7 — 31	3.2
21		“		1796, Feb. 1	13; 7	3.3
22		“		“ “	13. 7 —, 31	3.1
23		“		1796, Nov. 30	13 —, 123 Tauri, 7	3.2
24	II.	ζ Geminorum	43	1795, Nov. 7	55. 77, 34 — 43	4.1
25	III.	δ Cephei	27	1796, Nov. 5	32, 27	3.8
26	IV.	β Lyræ	10	1782, May 12		—
27		“		1795, May 5		—
28		“		1795, Sept. 15	14 —, 10	3.8
29	IV.	R Lyræ	13	1796, Aug. 28	12. 13	4.5
30		“		“ “	21. 20, 13	4.7
31	IV.	ρ Persei	25	1795, Aug. 21	23, 25 — 41, 46	3.4
32		“		1796, Sept. 7	45 — — 39 — 25	3.6
33	IV.	λ Tauri	35	1796, Jan. 1	1 — 2, 35. 38	4.0
34		“		1796, Nov. 30	123 —, 35	3.6
35	V.	X Sagittarii	3	1795, Sept. 15	2, 3	—
36	VI.	δ Libræ		1795, May 11	37, 31. 35, 44. 19. 43. 45. 6	5.2
37		“		1795, May 18	37, 31, 19	5.4
38		“		“ “	7, 19	5.6
39		“		1797, May 22	19. 18	5.9

The following remarks appear in the original record: —

No. 16. “ *o Ceti* is less than β and larger than α. See p. 26.”

No. 22. “ Seems to be larger than it has been.”

No. 26. “To the n-eye γ much larger than β. (Mem. This star is changeable, and was then at its minimum.)”

No. 27. “ β *Lyræ* much less than γ, $10^h\ 45^m$ com. time.”

No. 28. “ 10 seems to be at its minimum.”

The variations of several of these stars are irregular, or at least the law governing them is not yet known. It is evident that these observations will hereafter form a most valuable test of the correctness of any assumed law, since in many cases they precede by more than half a century any other observations of these stars of the same degree of precision. This is shown in Table II., which gives in successive columns the name of the star, the number of observations contained in Table I., the year in which the variability was discovered, and the number of years by which this followed the observations of Herschel. A dash is inserted when the discovery preceded the observations. In these cases the observations of Herschel have less value, since we have contemporaneous or antecedent observations which serve to determine the nature of the changes. The last three columns give the period in days, and the magnitude at maximum and minimum, according to the catalogue of Professor Schönfeld.*

TABLE II.

Name of Star.	No. Obs.	Discov.	Years.	Period.	Variation. Schönfeld.	
η Aquilæ	4	1784	—	7.2	3.5	4.7
g Herculis	8	1857	62	irr.	5	6.2
u Herculis	5	1869	74	irr.	4.6	5.4
o Ceti	3	1596	—	331.3	1.7–5.0	8–9
η Geminorum	9	1865	70	229.1	3.2	3.7–4.2
ζ Geminorum	1	1844	49	10.2	3.7	4.5
δ Cephei	1	1784	—	5.3	3.7	4.9
β Lyræ	3	1784	—	12.8	3.4	4.5
R Lyræ	2	1856	60	46.0	4.3	4.6
ρ Persei	3	1854	59	irr.	3.4	4.2
λ Tauri	3	1848	52	3.9	3.4	4.2
X Sagittarii	1	1866	71	7.0	4	6
δ Libræ	5	1859	64	2.3	4.9	6.1

The individual stars will now be considered in turn, so far as the material exists for a more complete reduction than is given in Table I.

η *Aquilæ.* — The variation in light of this star has been discussed by Argelander.† A light curve is given by which the brightness at any time may be expressed in terms of an arbitrary scale of grades. This scale is defined by expressing in grades the light of the comparison stars used in determining the changes in brightness of the variable. Points have been constructed for each of these stars, with grades as abscissas, and the photometric magnitudes as ordinates. A straight line drawn nearly through these points serves to convert the scale of grades into photometric magnitudes, or into actual light ratios. From this we may conclude that the maximum and minimum light of the variable expressed in photometric magnitudes is 3.7 and 4.5. The range is accordingly less than that ordinarily given, but this is partly due to the difference in the scales. The observations of Herschel expressed in grades equal 9.6, 6.1, 8.5, and 1.0. The first three of these correspond to periods of $1^d\ 19^h$, $1^d\ 4^h$, and $1^d\ 14^h$, after a minimum, if the light of the star was increasing, or to $3^d\ 4^h$, $5^d\ 6^h$, and $3^d\ 14^h$, if the light was diminishing. The other observation, No. 4, which was made six days later, on July 25, serves to decide between these two hypotheses. The light was then sensibly that of a minimum at 1.2 grades. As the period of the star is about $7^d\ 4^h$, a minimum about a day preceding the observations 1, 2, and 3 would also be indicated by observation 4. This would agree with the hypothesis that the light was increasing on July 19, but would controvert the view that it was diminishing.

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* Zweiter Catalog von veränderlichen Sternen. Mannheim, 1875.

† Astron. Nach., xix. 399.

The time of the observations is defined only by the limits of twilight, which in the latitude of Slough would extend to within about two hours of midnight in July. The star would culminate near midnight, and could be easily observed as long as darkness lasted. The times of observation may therefore be written, 1795, July $19^d\ 12^h \pm 2^h$, and 1795, July $25^d\ 12^h \pm 2^h$. The mean of the three results on July 19 would give an interval from the minimum of $1^d\ 12^h$, or would place the preceding minimum at 1795, July $18^d\ 0^h$, with an uncertainty of several hours, since a small error in the light corresponds to a large deviation in the time of minimum. The elements of Argelander indicate a minimum 1795, July $18^d\ 19^h\ 42^m$ Paris M. T.

g Herculis. — The variations in light of this star are irregular, or the law governing them has not yet been discovered. Should this law ever be determined, these observations may have great value, since they anticipate by sixty-two years the first observations of equal accuracy previously known. Probably the variations are so slow that the hour at which the observations were made will not be needed.

u Herculis. — The same remark applies to this star as to the preceding. The observations are accordant, and anticipate other similar observations by seventy-four years.

o Ceti. — Some other observations by Sir William Herschel are given by Argelander.* As this star had been observed for many years previously, these observations are not of especial importance.

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* Bonn Beob., vii. 329.

η Geminorum. — These observations precede by seventy years those taken elsewhere. They will therefore have great value in determining the period when the nature of the variations is more accurately established. The small change in light, however, makes the result derived from any small number of observations somewhat doubtful.

ζ Geminorum. — A comparison of the results obtained by Argelander * with the photometric measures gives the variation in light of this star from 3.6 to 4.2. It was therefore apparently observed by Herschel near its minimum. The light curve indicates that the observation preceded or followed a minimum by about nineteen hours, but the change in brightness during this time is much less than the uncertainty of the observation. The ephemeris of Schönfeld indicates a minimum for Ep. —2434 at 1795, Nov. 8^d $5^h.6$, which does not differ from the time of observation by as much as the uncertainty of the comparison.

δ Cephei. — According to the curve of Argelander,† this star has the magnitudes of 3.5 and 4.3 at maximum and minimum. The observation of Herschel would correspond to 8.0 grades. This indicates a minimum preceding it by 1^d 2^h or 2^d 20^h, according as the light was increasing or decreasing. The star is above the horizon nearly all night, hence the time of observation is fixed only by the limits of twilight. We may therefore call the time of observation, 1796, Nov. 5^d $12^h \pm 6^h$. The elements of Schönfield give for Ep. —2987 a minimum at 1796, Nov. 4^d 7^h 24^m, which agrees as well as could be desired with the observation. As in the case of *η Aquilæ*, the observations of contemporaneous observers fix the period of this star so accurately that a correction based upon a small number of observations does not seem justifiable.

β Lyræ. — The variations of this star have been so thoroughly determined by other observers that these observations cannot add much to our knowledge of the subject. Only one observation, No. 28 of Table I., is sufficiently precise to be of value, and the interval here employed —, is too large to be estimated with accuracy. This observation has therefore not been reduced.

R *Lyræ.* — The variations of this star are so small that it is doubtful if the observations of Herschel can be utilized.

ρ Persei. — The same remark may be applied to this star as to *g Herculis.*

λ Tauri. — This star belongs to the Algol class. The maximum brightness as given in the photometric catalogue is 3.6. The agreement of the observation No. 34 is probably accidental, since the large interval —, cannot be estimated with accuracy. As far as it goes, however, it indicates that the star was at its full brightness. The other observation, No. 33, indicates a diminution of light, or that the star was near a minimum. The law of variation of light is not known, but probably the change in magnitude amounts to about 0.8. The star retains its full brightness except for about two hours before and after each minimum. We may accordingly assume that a minimum preceded or followed the observation No. 33 by about one hour. On this day the sun set at about $3^h\ 47^m$ and λ *Tauri* set at $16^h\ 10^m$. Allowing for twilight, we may accordingly assume 1796, Jan. $1^d\ 10^h \pm 5^h$ for the time of observation. For the other date we obtain, in like manner, 1796, Nov. $30^d\ 11^h \pm 6^h$. The ephemeris of Schönfeld, applying the equation of light, gives 1795, Dec. $31^d\ 22^h.6$, for Ep. —6500. A correction to the ephemeris of $—11^h.5$ is thus indicated. This exceeds the possible error in the time, added to the probable error in magnitude. In other words, if the star was really below its full brightness, the minimum must have occurred several hours after the computed time. In like manner, we obtain 1796, Dec. $1^d\ 22^h.3$ for Ep. —6485, or the nearest minimum does not occur until 35 hours after the observation No. 34. Accordingly, as the observation indicated, the star should have had its full brightness. The first minimum previously known of this star occurred on Dec. 6, 1848. If it were possible to determine the hour of Herschel's observation, the mean period of this star would be determined with great precision. An uncertainty of one hour would correspond to about half a second in a single period.

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* Bonn Beob., vii. 389.

† Astron. Nach., xix. 395.

X *Sagittarii.* — This star varies in light from about 4.5 to 5.3 in a period of a little over seven days. The only comparison made by Herschel places this star a little fainter than 2 *Sagittarii.* The latter star is commonly placed in Ophiuchus, — in fact, it is nearly in line with 52 and 58 *Ophiuchi*, and between them. Its magnitude, according to the Uranometria Argentina is 6.8, which corresponds to 6.6 on the photometric scale. This would make the variable much too faint, even if at its minimum. It is also strange that Herschel should have employed a star at so great a distance (about 8°), when he might have taken others about equally faint and nearer. The hypothesis that 2 *Sagittarii* was much brighter then than now, is negatived by the fact that Herschel compared it with 52 *Ophiuchi*, and found it only slightly brighter. The magnitude of this star in the Uranometria

Argentina is 6.5, corresponding to a photometric magnitude of 6.3. This value, although reducing the discrepancy, would still make the variable 6.5, which is 0.7 fainter than its light at minimum. This comparison is not given in the catalogue of Herschel, and accordingly is not checked by appearing under both 2 and 3 *Sagittarii.*

The southern declination of the star restricts the time of observation within narrow limits. The star sets at 9^h, and twilight would not be over until about 7^h. Accordingly, the time of observation would be 1795, Sept. $15^d\ 8^h \pm 1^h$. The elements of Schönfeld* give a minimum at 1795, Sept. $15^d\ 16^h$, for Ep. —3902. The period of Schmidt,† on the other hand, gives 1795, Sept. $13^d\ 22^h$. If, then, the star was really at its minimum when observed by Herschel, this observation determines a correction to the period with great certainty.

δ *Libræ.* — The observations of this star are so important that they require a more detailed discussion. The law of variation of the light has been determined by Professor Schönfeld.‡ Table III. gives the names of the various comparison stars, the letters by which they are designated by Professor Schönfeld, and the brightness in grades that he assigned to them. The next columns give the light according to the photometric measures made at this Observatory, and according to the Uranometria Argentina. The grades are reduced to magnitudes, as described on page 271, according to each of the scales. The results found by subtracting the magnitudes derived from the grades from that given in the two catalogues are given in the last two columns.

TABLE III.

Names.	Desig.	Grades.	H. P.	U. A.	H. P.	U. A.
37 Libræ	*f*	15.2	4.9	5.5	—2	—2
ε Libræ	*e*	12.5	5.2	5.5	—2	0
15 Hev.	*d*	8.5	5.0	5.6	+3	+3
178 Bode	*c*	3.5	5.6	6.2	0	+1
B. A. C. 4945	*b*	0.0	—	6.6	—	0

The light of the variable at maximum and minimum equals 13.0 and 2.0 grades respectively. This corresponds to a variation from 4.9 to 5.8 on the photometric scale, and from 5.5 to 6.4 on the scale of the Uranometria Argentina.

The observations of Sir William Herschel are compared in Table IV.

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[*] Zweiter Catalog.

[†] Astron. Nach., lxxxvii. 109.

[‡] Astron. Nach., lxxiv. 342.

The successive columns give the Flamsteed numbers, the photometric magnitudes, and the magnitudes according to Sir William Herschel. These have been derived from a discussion of all six catalogues of Herschel. They have a special value for the present purpose, since they indicate the brightness of these stars at the time the observations now under consideration were made. The fourth column gives the magnitude according to the Uranometria Argentina. The magnitude of 19, δ *Libræ*, according to each of these scales is inserted in brackets.

TABLE IV.

Fl.	H. P.	W. H.	U. A.	Fl.	H. P.	W. H.	U. A.
37	4.9	5.1	5.5	37	4.9	5.1	5.5
31	5.2	5.0	5.5	31	5.2	5.0	5.5
35	5.4	5.9	5.8	19	[5.4]	[5.2]	[5.7]
44	5.5	5.4	5.9	7	5.4	5.0	5.7
19	[5.2]	[5.1]	[5.7]	19	[5.6]	[5.2]	[5.9]
43	5.0	4.8	5.5	19	—	[5.9]	[6.2]
45	5.0	5.2	5.5	18	—	6.0	6.3

The scale of the Uranometria Argentina differs two or three tenths of a magnitude from that of the photometer for stars of the fifth and sixth magnitude. For the stars used in this comparison the difference amounts to four tenths of a magnitude. Applying this correction, the results become more readily comparable without affecting the conclusions derived from them. In Table V. the brightness of δ at the time of the various observations, and at maximum and minimum, as stated in the first column, is compared. The following columns give the magnitude derived in Table IV. from the three authorities, after applying a correction of four tenths of a magnitude to the Uranometria Argentina. The last column gives a mean value which may be employed, since all the observations have been reduced to the same scale.

TABLE V.

	H. P.	W. H.	U. A.	Mean.
1795, May 11	5.2	5.1	5.3	5.2
1795, May 18	5.4	5.2	5.3	5.3
" "	5.6	5.2	5.5	5.4
1797, May 22	—	5.9	5.8	5.8
Maximum	4.9	—	5.1	5.0
Minimum	5.8	—	6.0	5.9

A minimum is clearly indicated in 1797, May 22, and the star seems to have been below its maximum brightness on the other nights also. Converting the magnitudes into grades, and comparing with the light curve of Professor Schönfeld, we may infer that on 1795, May 11, the observation was made $4^h.7$ before, or $5^h.2$ after, a minimum. The observations of 1795, May 18, in like manner, indicate that a minimum would follow in $3^h.4$, or had passed $3^h.8$. The observation of 1797, May 22, indicates a brightness that does not differ sensibly from that at minimum. The star changes in brightness by about a tenth of a magnitude within an hour of minimum.

The hours within which the observations must have been made are limited by the twilight, which would, for observations of such faint stars, be appreciable within two hours of midnight. The comparison stars 43 and 44 *Libræ* would be above the horizon from $8^h.0$ to $16^h.4$. Their altitudes would exceed 10° from $9^h.2$ to $15^h.2$.

The period of δ *Libræ* is $2^d\ 7^h\ 51^m\ 20^s = 2^d.3273148$. Accordingly, if a minimum occurred near midnight on 1797, May 22, others would have occurred on the afternoons of 1795, May 11, and 1795, May 18. We may therefore assume that the observations of 1795 were made after, and not before minima. Subtracting from the time 1795, May $11^d\ 12^h$, the interval $5^h.2$, adding $0^h.2$ for the difference in longitude of Slough and Paris, and adding $0^h.1$ for the equation of light, we obtain 1795, May $11^d\ 7^h.1$, for the Paris heliocentric time of minimum. The times of minima indicated for the other observations are given with this in the first column of Table VI. The second column gives the ephemeris time for the epoch given in the third column. The last column gives the observed minus the computed times of minima.

TABLE VI.

Observed.	Computed.	Epoch.	O. — C.
d. h.	d. h.		h.
1795, May 11 7.1	May 11 11.9	—10980	—4.8
1795, May 18 8.5	May 18 11.5	—10977	—3.0
1797, May 22 12.3	May 22 21.8	—10661	—9.5

The mean of these results indicates a correction of six hours to the ephemeris, or of seven hours, if we assign somewhat greater weight to the last observation. A most fortunate coincidence brought all the observations so near minimum that the star had in each case less than its normal light. Observations of the maximum light would have had comparatively little value.

The times of minima on May 11 and May 18, 1795, are somewhat uncertain, since the assumed light of the comparison stars may be in error. All the stars with which δ *Libræ* was compared have accordingly been arranged in sequences by Mr. Chandler, since the above reduction has been made. The details of these observations will be published elsewhere, but they give a correction for the minima of May 11 and May 18 of —2.3 and —2.5, instead of —4.8 and —3.0 hours.